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September 24, 1997

FINAL

SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT FOR THE CASSINI MISSION

Office of Space Science
National Aeronautics and Space Administration
Washington, DC 20546

June 1997

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ABSTRACT

LEAD AGENCY:	National Aeronautics and Space Administration Washington, DC 20546
COOPERATING AGENCY:	U.S. Department of Energy Washington, DC 20585
POINT OF CONTACT FOR INFORMATION:	Mr. Mark R. Dahl Office of Space Science (Code SD) NASA Headquarters Washington, DC 20546-0001 (202) 358-1544
DATE:	June 1997

This supplement to the 1995 Cassini mission Environmental Impact Statement (EIS) focuses on information recently made available from updated mission safety analyses. This information is pertinent to the consequence and risk analyses of potential accidents during the launch and cruise phases of the mission that were addressed in the EIS. The type of accidents evaluated are those which could potentially result in a release of plutonium dioxide from the three Radioisotope Thermoelectric Generators (RTGs) and the up to 129 Radioisotope Heater Units (RHUs) onboard the Cassini spacecraft. The RTGs use the heat of decay of plutonium dioxide to generate electric power for the spacecraft and instruments. The RHUs, each of which contains a small amount of plutonium dioxide, provide heat for controlling the thermal environment of the spacecraft and several of its instruments.

Consistent with the commitment it made in the EIS, the National Aeronautics and Space Administration (NASA) has evaluated the information recently made available and has determined that preparation of this Supplemental Environmental Impact Statement (SEIS) for the Cassini mission will further the purposes of the National Environmental Policy Act (NEPA).

The planned Cassini mission is an international cooperative effort of NASA, the European Space Agency, and the Italian Space Agency to explore the planet Saturn and its environment. The Cassini mission is an important part of NASA's program for exploration of the solar system, the goal of which is to understand the system's birth and evolution. The Cassini mission would involve a four-year scientific exploration of Saturn, its atmosphere, moons, rings and magnetosphere. The scientific information gathered by the Cassini mission could help provide clues to the evolution of the solar system and the origin of life on Earth.

The Cassini EIS was made available to Federal, state and local agencies, the public and other interested parties on July 21, 1995. In addition to the No-Action Alternative, the 1995 Cassini EIS addressed, in detail, three alternatives for completing preparations for and operating the Cassini mission to Saturn and its moons. On October 20, 1995, utilizing the analyses in the 1995 Cassini EIS, along with other important considerations, such as programmatic, technical, economic, and international relations, the Record of Decision (ROD) selecting the Proposed Action was rendered.

The Proposed Action and preferred alternative addressed in this SEIS consists of completing preparation for and operating the Cassini mission to Saturn and its moons, with a launch of the Cassini spacecraft onboard a Titan IV (SRMU)/Centaur. The launch would take place at Cape Canaveral Air Station (CCAS) during the primary launch opportunity in October-November 1997. A secondary launch opportunity occurs in late November 1997-January 1998, with a backup opportunity in mid-March-April 1999, both using the Titan IV (SRMU)/Centaur. The primary launch opportunity would employ a Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to Saturn; the secondary and backup opportunities would both employ a Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory. The Proposed Action would allow the Cassini spacecraft to gather the full science return desired to accomplish mission objectives.

EXECUTIVE SUMMARY

This Supplemental Environmental Impact Statement (SEIS) has been prepared in accordance with the National Environmental Policy Act of 1969 (NEPA), as amended (42 U.S.C. 4321 et. seq.); the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of NEPA (40 CFR Parts 1500-1508); and the National Aeronautics and Space Administration's (NASA's) policy and procedures (14 CFR Subpart 1216.3) to support the decision-making process concerning the Proposed Action and alternatives for NASA's Cassini space exploration mission.

NASA completed development of the Cassini mission Environmental Impact Statement (hereafter denoted 1995 Cassini EIS) with distribution of the Final EIS to the public and other interested parties in July 1995. The Record of Decision (ROD) was rendered in October 1995. The 1995 Cassini EIS contained NASA's evaluation of the potential impacts of completing preparations for and implementing the Cassini mission, with particular emphasis on accidents that could potentially occur during launch and cruise phases of the mission, and which could impact human health and the environment. While the 1995 Cassini EIS analyses used the best information available at that time, the 1995 Cassini EIS noted that NASA and the U.S. Department of Energy (DOE) were continuing to analyze and evaluate additional accident scenarios specific to the Cassini spacecraft and its launch vehicle and trajectory. In both the 1995 Cassini EIS and the ROD, NASA made the commitment that, should significant differences arise between the results of the ongoing analyses and the 1995 Cassini EIS, NASA would evaluate the information and make a determination regarding the need for additional NEPA documentation, including supplementing the 1995 Cassini EIS. Updates of the safety analyses in support of the 1995 Cassini EIS were recently made available to NASA. NASA has evaluated those analyses accordingly, and has determined that the purposes of NEPA are furthered by preparation of this SEIS.

PURPOSE AND NEED FOR THE ACTION

The Cassini mission is an international cooperative effort of NASA, the European Space Agency (ESA), and the Italian Space Agency (ASI), to explore the planet Saturn and its environment. Saturn is the second-largest and second-most massive planet in the solar system, and has the largest, most visible, dynamic ring structure of all the planets. The mission is an important part of NASA's program for exploration of the solar system, the goal of which is to understand the system's birth and evolution. The Cassini mission involves a four-year scientific exploration of Saturn, its atmosphere, moons, rings and magnetosphere. The Cassini spacecraft consists of the Cassini Orbiter and the detachable Huygens Probe.

The Cassini mission represents an important step in the exploratory phase of planetary science, with the detailed data that would be obtained from the mission providing an important basis for continuing Earth-based studies of the planets. There are five major areas of investigation planned for the Cassini Mission. An overview of each area of investigation follows:

- The previous Pioneer and Voyager swingby missions to Saturn obtained only short-duration, remote-sensing measurements of the Saturnian atmosphere. These measurements have been sufficient to generally determine the basic composition, energy balance, temperature profile, and wind speeds in the planet's upper atmosphere. Cassini would further investigate cloud properties and atmospheric composition, wind patterns, and temperatures, as well as Saturn's internal structure, rotation, ionosphere, and origin and evolution. The missions would involve orbits near the equator and the poles of Saturn so that the entire planet could be studied.

- Titan is shrouded by dense clouds; therefore, little is known about its surface. Data collected by the instruments onboard the Cassini orbiter and the Huygens Probe would provide a better understanding of the abundance of elements and compounds in Titan's atmosphere, the distribution of trace gases and aerosols, winds and temperature, and surface state and composition. In particular, the spacecraft's radar would penetrate Titan's dense atmosphere and reveal the moon's surface characteristics. The Huygens Probe, carrying a robotic laboratory, would perform chemical analyses of Titan's atmosphere and clouds. As the Probe descends, the onboard instruments would measure the temperature, pressure, density, and energy balance through the atmosphere to the moon's surface. The surface properties would be measured remotely, and a camera would photograph the Titan panorama and relay the images to Earth via the Cassini Orbiter.

- Saturn's other satellites (i.e., moons) are ice-covered bodies. Cassini would investigate their physical characteristics, the composition and distribution of materials on their surfaces, their internal structure, and how they interact with Saturn's magnetosphere. Of particular interest is the half-dark and half-light moon, Iapetus. The light side of the moon is believed to be composed of ice and the dark side possibly of some organic material. The data obtained by Cassini would assist in determining the geological histories of the satellites and the evolution of their surface characteristics.

- The Voyager swingbys in 1980 and 1981 proved Saturn's ring system to be much more complex than previously realized, with intricate dynamic interactions in most parts of the system. The short-term Voyager studies showed a wide range of unexplained phenomena in the rings, including various wave patterns, small and large gaps, clumping of material and small, so-called "moonlets" embedded in the rings. Long-term, close-up observations of the rings by Cassini could help resolve whether the rings are material left over from Saturn's original formation, or whether they are remnants of one or more moons shattered by comet or meteor strikes. Applied to larger-scale disk-shaped systems, the detailed studies of Saturn's rings proposed for Cassini would provide important contributions to theories of the origin and evolution of the dust and gas from which the planets first formed.

The tilt of Saturn's ring plane changes as the planet orbits the Sun and the changing angle of sunlight illuminating the rings dramatically alters their visibility. Cassini's arrival at Saturn is timed for optimum viewing of the rings, during a period when they will be well illuminated by sunlight. Upon Cassini's arrival at Saturn in 2004 when launched in October 1997, the tilt of the ring plane and resulting illumination angle would allow Cassini's instruments an unsurpassed view of the ring disk.

Cassini would allow detailed studies of ring structure and composition, dynamic processes, dust and micrometeoroid environments, and interactions among the ring systems, magnetosphere, and satellites.

- Saturn's magnetosphere is the region of space under the dominant influence of the planet's magnetic field. Cassini would carry instruments to study the configuration and dynamics of the magnetosphere; the nature, source, and fate of its trapped particles; and its interactions with the solar wind and Saturn's satellites and rings. A particular phenomenon of interest is the Saturn Kilometric Radiation—a poorly understood, very low frequency, electromagnetic radiation—which scientists believe is emitted by the auroral regions in Saturn's high latitudes.

Implementation of the proposed action would also ensure that the spacecraft would complete its orbital tour before 2010, when Saturn's rings would present themselves nearly edge-on to the Earth and Sun, severely limiting the ability for detailed observations.

The Cassini spacecraft incorporates three (3) Radioisotope Thermoelectric Generators (RTGs) to provide onboard electric power for spacecraft operation and scientific instruments. The RTGs generate electric power by utilizing the heat from decay of radioactive material. The material is an isotopic mixture of plutonium in the form of dioxide, along with small amounts of long-lived actinides and other impurities. About 71 percent of the oxide mixture (by weight) is plutonium-238 (Pu-238). The three RTGs onboard the Cassini spacecraft contain a total of 32.7 kg (about 72 lb) of PuO_2, amounting to 1.49×10^{16} Bq (402,000 Ci). In addition, 129 Radioisotope Heater Units (RHUs) will be employed to regulate the temperature inside the spacecraft and for several instruments. Each RHU contains about 2.7 gm (0.006 lb) of mostly plutonium-238 dioxide, amounting to a collective total of about 0.35 kg (0.77 lb), or about 1.48×10^{14} Bq (4,000 Ci) of radioactive material in the 129 RHUs.

The 1995 Cassini EIS was made available to Federal, state and local agencies, the public and other interested parties on July 21, 1995. In addition to the No-Action Alternative, the 1995 Cassini EIS addressed three alternatives for completing preparations for and operating the Cassini mission to Saturn and its moons. On October 20, 1995, utilizing the impact analyses in the EIS, along with other important considerations such as programmatic, economic, and international relations, the ROD selecting the Proposed Action was rendered.

ALTERNATIVES EVALUATED

The Proposed Action and preferred alternative consists of completing preparations for and operating the Cassini mission to Saturn and its moons, with a launch of the Cassini spacecraft onboard a Titan IV(SRMU)/Centaur. The launch would take place at Cape Canaveral Air Station (CCAS) during the primary launch opportunity of October 6 through November 15, 1997. A secondary launch opportunity occurs from late November 1997 through early January 1998, with a backup opportunity from mid-March to early April 1999, both using the Titan IV(SRMU)/Centaur. The primary launch opportunity would employ a Venus-Venus-Earth-Jupiter-Gravity-Assist (VVEJGA) trajectory to Saturn; the secondary and backup opportunities would both employ a Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory. The Proposed Action would allow the Cassini spacecraft to gather the full science return desired to accomplish mission objectives.

Along with the No-Action Alternative, the 1995 Cassini EIS evaluated two other mission alternatives. The March 1999 Alternative would have used two Shuttle flights launched from Kennedy Space Center (KSC), with on-orbit integration of the spacecraft and upper stage, followed by injection of the spacecraft into a VEEGA trajectory to Saturn. The March 1999 Alternative is no longer considered reasonable at this time due to the long lead-time in developing and certifying the new upper stage that would be needed to implement this mission alternative. When combined with the significant additional costs associated with this alternative, the 1999 dual Shuttle alternative is no longer considered reasonable.

The other mission alternative evaluated in the 1995 Cassini EIS was the 2001 Alternative, which would use a Titan IV(SRMU)/Centaur to launch the spacecraft from CCAS in March 2001 using a Venus-Venus-Venus-Gravity-Assist (VVVGA) trajectory. A backup opportunity in May 2002 would use a VEEGA trajectory. The 2001 Alternative would require completing the development and testing of a new high-performance rhenium engine for the spacecraft, as well as adding about 20 percent more propellant to the spacecraft. Science returns from this alternative would meet the minimum acceptable level for the mission.

RADIOLOGICAL IMPACTS OF ACCIDENTS

Evaluation of the recently available safety analyses has indicated that the only parts of the previous Cassini EIS potentially affected are the analyses of the radiological consequences of accidents involving a potential release of plutonium dioxide (source term) from the RTGs and/or the RHUs onboard the spacecraft. The environmental impacts of completing preparations for the mission are unaffected by the updated analyses, and remain as presented in the 1995 Cassini EIS. In addition, the analyses of the environmental impacts of both an incident-free launch and incident-free interplanetary gravity-assist trajectory are also unaffected and remain as presented in the 1995 Cassini EIS.

The EIS's and recently available analyses overall assessments of the Cassini mission's risk are similar. The updated assessment of individual mission segment accidents has identified higher risks for launch segment accidents and lower risks for the Earth gravity assist (EGA) swingby segment. Both the EIS and the updated analyses indicate that only a fraction of conceivable launch accidents are calculated to result in releases of PuO_2.

The ongoing safety analysis process is similar to the process used for the earlier Galileo and Ulysses missions and has resulted in incremental improvements in the modeling and analysis techniques. The potential source terms are determined by using simulations to evaluate the response of the RTGs, RTG components, and RHUs to the defined accident environments. The ongoing analyses utilize probabilistic risk assessment techniques with computer simulation and modeling of RTG responses to accident environments, and are based upon safety test and analysis studies performed by and on behalf of DOE. The safety test and analysis studies have been performed over the past 12 years on General Purpose Heat Source (GPHS) RTGs and materials, and RHUs. These tests provide a database of the performance response of the RTGs and RHUs to simulated accident conditions such as high-velocity impacts on hard surfaces, impacts from high-velocity fragments, and exposure to thermal and mechanical stresses such as would be encountered in a reentry from Earth orbit or exposure to burning solid rocket motor propellant. It must be emphasized that for a release of plutonium dioxide (PuO_2) to occur, the initiating accident must be followed by other events to create an accident environment that threatens the integrity of the RTGs and RHUs.

Since the issuance of the 1995 Cassini EIS, the refinements in the evaluation of accidents and estimation of their potential consequences have resulted in revised estimates. Comparison between the 1995 Cassini EIS results and the updated results are presented in this SEIS. The 1995 Cassini EIS reported point estimates of the "expectation" and "maximum" cases. The expectation case utilized source terms for each accident scenario that were probability-weighted, and was based upon a range of release conditions considered in the analysis. The maximum case utilized source terms that corresponded to either the upper limit deemed credible for the scenario, based on consideration of supporting analyses and safety test data, or to a total probability greater than or equal to a probability cutoff of $1x10^{-7}$ (1 in 10 million). The updated analyses used probabilistic risk assessment techniques similar to those used for the Galileo and Ulysses missions to generate updated estimates of consequences and risk.

The 1995 Cassini EIS utilized the concept of risk as one of the key measures in the accident analyses. Risk, for the purpose of the 1995 Cassini EIS and for this supplement, is defined as the total probability of an event occurring (i.e., a release from an RTG or RHU), multiplied by the mean consequence of the event (i.e., health effects described as latent cancer fatalities over a 50-year period within the population potentially exposed by an accident). With respect to the Cassini accident analyses, the total probability of a release occurring is determined by multiplying the probability of the initiating accident that could threaten the RTGs and RHUs, times the conditional probability that the accident will result in a release. Risk estimates for the Cassini mission (expressed as health effects) have been developed for each mission phase/accident scenario and for the average exposed individual. The updated analyses report the best estimate of consequences and risks. While the overall probability of an accident that could threaten the RTGs or RHUs during the Cassini mission is 2.8×10^{-2}, or 1 in 36, the probability of an accident predicted to release PuO_2 is 2.8×10^{-3}, or less than 1 in 357. Such an accident could result in 0.089 mean health effects. This results in an overall mission risk of 2.5×10^{-4}, or 0.00025, health effects worldwide. This risk level is lower than the overall risk reported in the 1995 Cassini EIS (expected value of 1.7×10^{-3}, or 0.0017, health effects).

The total mission risk is distributed over four major mission segments--i.e., pre-launch (Phase 0), early launch (Phases 1 and 2), late launch (Phases 3 - 8) and Earth Gravity Assist (EGA). The pre-launch segment runs from 48 hours (T-48 hrs) prior to launch to T-0 seconds (s). The early launch segment starts with ignition of the SRMUs at T-0 s and extends through T+143 s when the SRMUs are jettisoned. The time period from T+143 s to T+206 s is not considered because there are no accidents that could result in a release of PuO_2 during this time period of the mission. The late launch segment starts at T+206 s and extends to the point where the spacecraft has escaped from Earth orbit. The EGA segment encompasses the period from Earth escape to completion of the Earth swingby.

Pre-launch accidents were not covered in the 1995 Cassini EIS because, at that time, none were postulated that could result in a release of PuO_2. However, information recently made available from the updated mission safety analyses indicates the total probability of a pre-launch accident that results in a release of PuO_2 is 5.2×10^{-5}, or about 1 in 19,200, and could result in 0.11 mean health effects and could contaminate 1.5 km^2 (0.58 mi^2) of land above 7.4×10^3 Bq/m^2 (0.2 $\mu Ci/m^2$) (the Environmental Protection Agency's [EPA's] guideline level for considering the need for further action).

The total probability of an early launch accident that results in a release of plutonium is 6.7×10^{-4}, or about 1 in 1,490, and could result in 0.082 mean health effects and could contaminate 1.6 km^2 (0.62 mi^2) of land above the EPA guideline level. In comparison to the 1995 Cassini EIS, this segment's mean mission risk is 0.000055 health effects, which exceeds the 1995 Cassini EIS estimate of 0.00000046.

The total probability of a late launch accident that results in a release of plutonium is 2.1×10^{-3}, or 1 in 476, and could result in 0.044 mean health effects and could contaminate 0.057 km^2 (0.02 mi^2) of land above the EPA guideline level. In comparison to the 1995 Cassini EIS, this segment's mean mission risk is 0.000092 health effects, which exceeds the 1995 Cassini EIS estimate of 0.00000037.

The total probability of an EGA accident that results in a release of plutonium is $8.0x10^{-7}$, or less than 1 in 1 million, and could result in 120 mean health effects and could contaminate 15 km^2 (5.8 mi^2) of land above the EPA guideline level. In comparison to the 1995 Cassini EIS, this segment's mean mission risk is 0.000098 health effects, which is less than the 1995 Cassini EIS estimate of 0.0017.

In addition to these new best estimate analyses, DOE has conducted a study of the uncertainty in the underlying test data and models used to estimate accident risks and consequences. This information is presented in Chapter 4 of this SEIS.

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LIST OF ACRONYMS

A

ADS	Automatic Destruct System
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
AU	astronomical unit(s)

B

Bq	Becquerel

C

^{o}C	degrees Centigrade (Celsius)
CBCF	carbon-bonded carbon fiber
CCAS	Cape Canaveral Air Station
Ci	curie
cm	centimeter
cm^3	cubic centimeters
CSD	Command Shutdown and Destruct
CSDS	Command Shutdown and Destruct System

D

DCU	digital control unit
DEIS	Draft Environmental Impact Statement
DOD	Department of Defense
DOE	Department of Energy

E

EGA	Earth-Gravity-Assist
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
ESA	European Space Agency

F

FCO	Flight Control Officer
FSEIS	Final Supplemental Environmental Impact Statement
ft/s	feet per second
FTS	Flight Termination System

G

g	gram
GaAs	gallium arsenide
GIS	Graphite Impact Shell
GPHS	General Purpose Heat Source

LIST OF ACRONYMS (continued)

H

H_2	hydrogen
ha	hectare
HNUS	Halliburton NUS
HTPB	hydroxyl terminated polybutadiene

I

ICRP	International Commission on Radiological Protection
IIP	instantaneous impact point

J

JPL	Jet Propulsion Laboratory, California Institute of Technology

K

kg	kilogram(s)
km/s	kilometers per second
km^2	square kilometer(s)
KSC	Kennedy Space Center, NASA

L

LASEP-T	Launch Accident Scenario Evaluation Program-Titan IV/Centaur
lb	pound(s)
LEO	low earth orbit
LH_2	liquid hydrogen
LILT	low (insolation) intensity and low temperature
LIS	Laser Illumination System
LO_2	liquid oxygen
LWRHU	Light-weight Radioisotope Heater Units (same as RHUs)

M

MECO	Main Engine Cutoff
MET	mission elapsed time
mi	miles
mm	millimeter
MMH	monomethylhydrazine
mrem	millirem
m/s	meters per second
$\mu Ci/m^2$	µCi per square meter
µCi	µCi
$\mu g/m^3$	micrograms per cubic meter

LIST OF ACRONYMS (continued)

N

N	Newton
N_2H_4	hydrazine
N_2O_4	nitrogen tetroxide (NTO)
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection and Measurements
NEPA	National Environmental Policy Act
NO_2	nitrogen dioxide
NOI	Notice of Intent
NTO	nitrogen tetroxide (N_2O_4)

O

O_2	oxygen
O_3	ozone

P

PG	pyrolytic graphite
PLF	Payload Fairing
PMS	Propulsion Module Subsystem
POF	probability of failure
psi	pounds per square inch
Pt	platinum
Pu	plutonium
PuO_2	plutonium dioxide

R

rem	roentgen equivalent man
RHU	Radioisotope Heater Unit (same as LWRHU)
ROCC	Range Operation Control Center
ROD	Record of Decision
RSAS	Range Safety Advisory System
RTG	Radioisotope Thermoelectric Generator

S

s	seconds
SEIS	Supplemental Environmental Impact Statement
SRMU	Solid Rocket Motor Upgrade
Sv	Sievert
SV	Satellite Vehicle
SVDS	Space Vehicle Destruct System

LIST OF ACRONYMS (continued)

T

TBVD	Total Boost Vehicle Destruct
T	Time relative to ignition at launch

U

UDMH	unsymmetrical dimethylhydrazine
USAF	United States Air Force

V

VEEGA	Venus-Earth-Earth-Gravity Assist
VVEJGA	Venus-Venus-Earth-Jupiter-Gravity-Assist
VVVGA	Venus-Venus-Venus-Gravity-Assist

W

W	Watt

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